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COMMONWEALTH OF PENNSYLVANIA

DEPARTMENT OF INTERNAL AFFAIRS

COAL

A Petrographic Approach

by

Edwin F. Koppe

TOPOGRAPHIC AND GEOLOGIC SURVEY

BULLETIN M 42

1960

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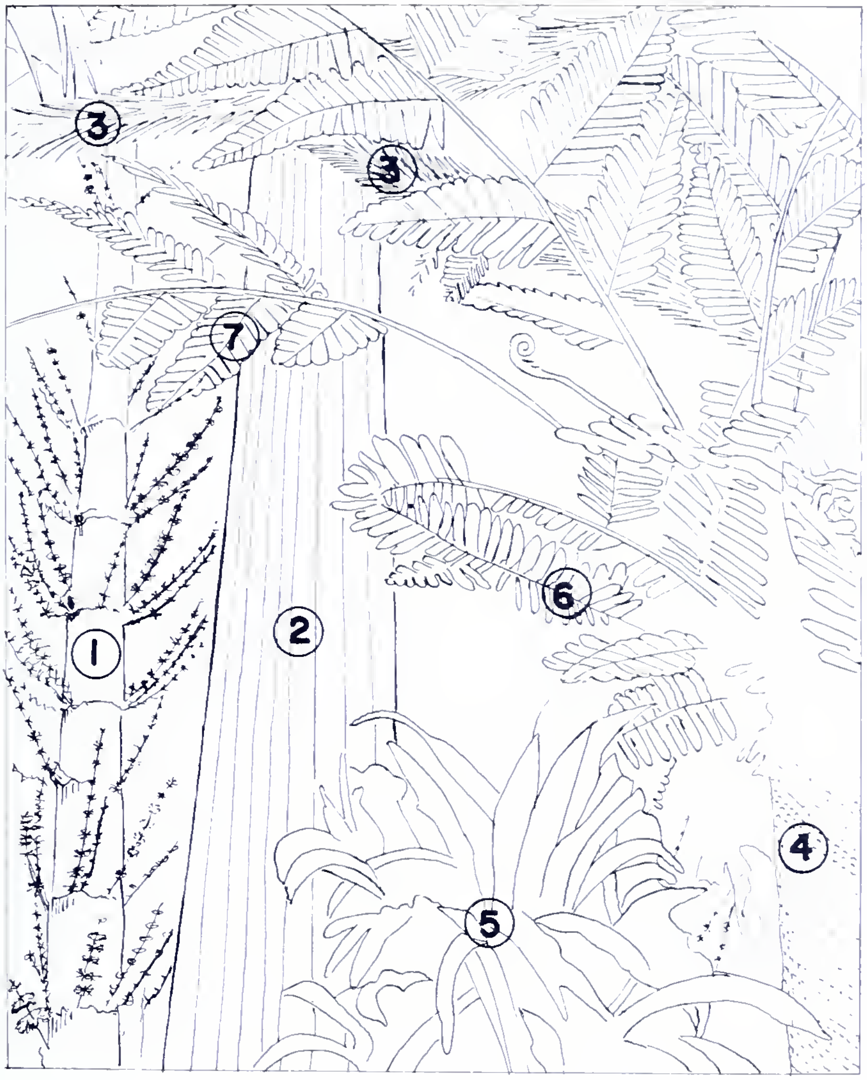

Paleozoic Coal-forming Plants. Carboniferous Forest Group (reconstruction) by Ottmar and Hanna von Fuehrer. Photograph reproduced courtesy of Carnegie Museum, Pittsburgh, Pa.

1. Calamites (ancient scouring rush)
2. Sigillaria (lycopod)
3. Lepidodendron leaves (lycopod)
4. Lepidodendron stem
5. Cordaites (ancient conifer)
6. Neuropteris (seed fern)
7. Pecopteris (fern)

FOREWORD

The Bureau of Topographic and Geologic Survey is devoting attention to the physical composition of the coals lying within the confines of the Commonwealth. Information basic to understanding Pennsylvania's coal resources has already been reported for several areas. The resultant publications contain geological information of the amount, distribution, description and structure of the coals.

Four additional objectives are now of concern. These are to determine: 1) the abundance of various coal components within each seam, 2) the local and regional distribution of the components, 3) the relation of components to beneficiation of the coal, and 4) the botanical aspects of coal as they are related to composition and stratigraphy of the coal beds and adjacent strata.

This publication was prepared with two purposes in mind. It is primarily an introduction to coal petrography for those unfamiliar with the subject. Second, it is intended to be a reference of methods and terminology for individuals who wish to examine critically forthcoming analyses of coal issued by this office.

Genevieve Blatt

Genevieve Blatt, Secretary
Department of Internal Affairs

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COAL, A PETROGRAPHIC APPROACH

by

Edwin F. Koppe

ABSTRACT

This publication contains an exposition of coal petrography and is potential value to coal utilization and research. Brief outlines of coal oigin and standard analytical methods used are presented. In addition, ptrographic nomenclature and techniques are discussed, both for field ad laboratory study. Photographic illustrations are employed to clarify te specialized terminology of the field, and a log of the Upper Freeport Coal Bed is included providing an example of information obtained through ptrographic examination.

INTRODUCTION

Coal is Pennsylvania's most important mineral resource. The gowth and expansion of the steel industry within the state was, and is, made possible by the abundant nearby coals suitable for use in steel manufacture. Every bit as important to Pennsylvania is the use of coal fr the production of electrical power. Now, with the Electric Age past i infancy, more coal will be required than ever before to produce the pwer needed in modern industry and modern living. Even the coming Aomic Age is not expected to replace coal, but rather to supplement it.

To many people, coal represents stored energy; energy which cn be converted to heat and power. To others, chemists particularily, cal is more, it is a warehouse stocked with a myriad of organic subsances. These can be separated or converted for the benefit of man as idustrial chemicals, liquid fuels, and basic synthetic resins for plastics ad other uses. To some, both views are necessary. In the steel industy, for example, coal is considered both as a source for energy and also a a source of a reactive chemical in the reduction of iron ore. To many gologists, coal is a product of plant material deposited in a sensitive evironment. In this capacity it serves as an aid in stratigraphic control, hlping to locate other valuable resources.

Coals are different from area to area in Pennsylvania. Hence, many changes of physical appearance and chemical composition are found. Tese composition changes must be known if the maximum benefit is to be otained from this important resource. One branch of coal science is cncerned with these changes. This special area of investigation is called Coal Petrography - the subject of this publication.

Coal petrography is basically "seeing" coal. Through this stu we learn three things. (1) We learn much about the black matter's pas that is, its origin and deposition. (2) We learn the present compositio and better ways of utilizing coal for present processes in our economy. And finally (3), we determine characteristics which need to be understo for future uses. These three facets are not completely separable; nor should they be. To understand coal in its present condition, the role of coal origin should be considered first.

COAL ORIGIN

Coal is composed of the remains of former plant life. Most Pennsylvanian coals were formed in widespread swamps somewhat like those found today in the southeastern United States, but the plants which gave rise to the coals were different from their modern counterparts. There were no true flowering plants. Instead, large ferns, lycopods a primitive ancestors of conifer trees dominated swampy environments a illustrated in the frontispiece.

It is from study of modern counterparts of coal-forming enviro- ments that we learn some details of the earliest stages of coal origin. swamps, plants grow generation after generation constantly contributin a surface litter to the water-soaked ground. Bacteria, fungi, root acti and other agencies partially decompose the organic material into peat. Fungal and aerobic bacterial decay takes place in the developing peat wherever oxygen is available, both above and below the water level. T organic matter not completely destroyed by the above agencies is furthe modified by the action of anaerobic bacteria well below the water table where little or no oxygen is available. These bacteria degrade some of the plant substances; but, in turn, they produce substances which redu the rate of decomposition. Together with the absence of oxygen, these substances create a toxic environment preventing complete destruction the organic mass.

As the rate of plant matter deposited exceeds the rate of degradation, a peat mat is formed. Plants which can grow rooted upon the peat soon take place of those which must be rooted in the other soils. Later, as the composition of the developing peat changes, other plants become dominant. In other words, the flora is changed to domination b species which thrive on a given peat substratum. Some trees, more tolerant to open water than others, grow in certain parts of the swamp for a while. This flora then loses ground to the invasion of another flo as the peat mass builds above the water level and drier conditions deve

The first group of plants may contribute a peat layer having m oody matter and bark. The succeeding flora may add layers of leaf ebris, cuticles and lesser amounts of wood over the first layer. Occa-onal open water conditions can give rise to a layer of organic ooze apropel) composed of finely divided debris with many spores and other sistent fragments. A thick peat deposit is usually spongy near the sur-ce and very often contains a dark red to brown watery mire at depth. ometimes floods wash in a thin layer of mud and silt over the peat. When dditional peat is deposited, this layer forms an inorganic "parting" in e peat marking the event.

Major flooding of the swamp will halt both the organic accumu-tion and the decay caused by aerobic organisms. In this case, a thick anket of mud, silt or sand buries and compresses the peat. The over-ing sediment becomes the coal roof. Much compressed, the peat layers e preserved as coal layers.

The first stage of coal formation discussed above, which includes at accumulation, a degree of biological decomposition, physical degra-ation, and stratification of the sediment, is called the biochemical stage. ith the burial of the organic deposit by muds, silts, sands, etc., which e deposited as the area is submerged, the second stage of coalification gins, the dynamochemical or metamorphic stage.

The weight of overlying inorganic sediments compacts the bed of ganic matter, driving off much water and some volatile matter. Re-aining biological activity (anaerobic degradation) is eventually halted as any chemical changes take place converting the material first to brown al or lignite and then to higher ranked coal. Pressure from sedimentary erburden and earth movements, time, and elevated temperatures com-ne to reduce the volatile matter and moisture content of the coal to its esent condition. The original peat is converted to anthracite or graphite areas which have been subjected to pronounced geological disturbance, essure, and/or heat, perhaps for long periods of time.

Coal metamorphism is a continuing process. At any stage, the gree of metamorphism is known as the coal rank. Rank generally is termined by chemical analysis for the entire coal bed. However, each ant tissue in the deposits is converted to a carbonaceous end product rough chemical sequences that are unique to the original tissue itself. ome pass through initial stages rapidly. Others, the waxy parts espe-ally, are but little changed until later in metamorphism. A single plant ssue often undergoes two or more different coalification sequences elding different substances at any given time. Thus, the present ma-rials in coal are the products of many factors.

The coals of eastern Pennsylvania (Figure 1) are primarily thracite because they were involved in extremely intense earth move-

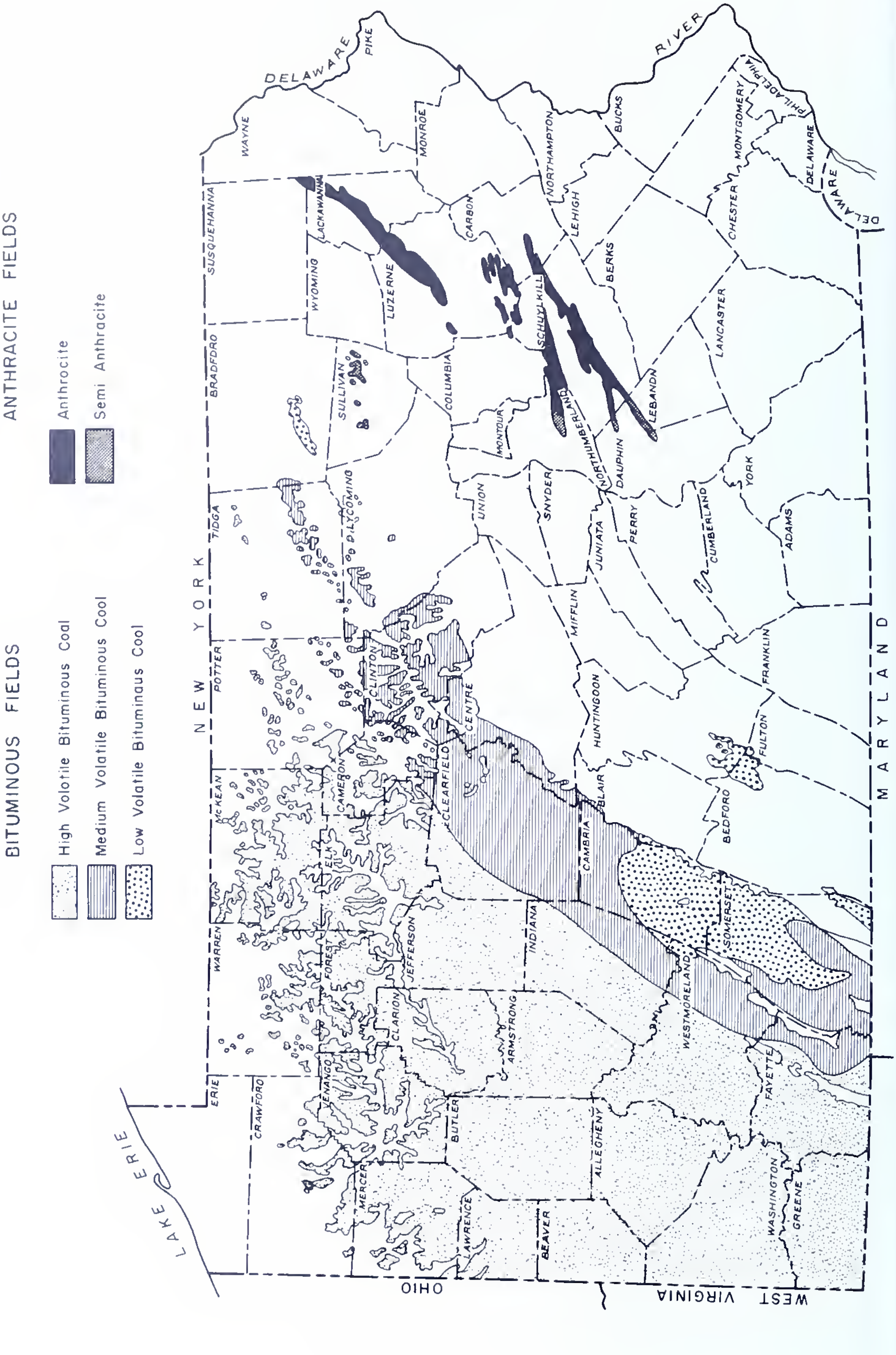

Figure 1. Distribution of Pennsylvania Coals

ents and pressure. Coals of western Pennsylvania are bituminous in nk; the original peat deposits having been subjected to lesser pressures d milder earth movement for approximately the same duration of time the anthracites.

COAL EXAMINATION

Advances in our knowledge about coal depend on adequate descrip-ons of the material. Various methods are used. Petrographic techniques e used to describe and characterize the coal by visual observation, ually by coupling normal visual description with microscopic examina-on. Chemical and physical tests are used to describe the material in rms of its chemical composition and its physical properties. The needs r any particular investigation determine the degree of emphasis to be aced upon each of the above descriptive methods.

Chemically, coal is characterized in its overall composition by o types of analyses. These may be termed composition and reaction alyses. An example of composition analysis is the "ultimate analysis". his chemical analysis of coal breaks down the components into total nounts of the contained elements as carbon, nitrogen, hydrogen, oxygen, lfur, etc., making up the organic portion of coal. Supplementary ele-ental analysis of the inorganic residue might also be obtained. Another ss familiar composition analysis measures the abundance of naturally curring substances extracted from the coal as waxes, resins and other ganic compounds. Composition analyses generally are obtained only by acting and costly chemical techniques.

Reaction analyses indicate the amounts and kinds of products sulting from heating or otherwise modifying the coal. The commonly countered "proximate analysis" provides a coal characterization of this pe. It yields a different type of information than an "ultimate analysis" d, furthermore, is more rapid and is much less expensive. Briefly ated, the proximate analysis describes coal in terms of:

Moisture - the moisture lost when the coal is heated to a given temper-ture (105°C) for a given period of time.

Volatile matter - the gases released upon greater application of heat (950°C) without permitting oxidation of the coal.

Fixed carbon - the volatile loss from the coal by burning (oxidizing) at 750°C minus the amount of volatile matter and moisture determined for the sample.

Ash - the residue after oxidation at 750°C.

Another important reaction test, the calorific analysis, indicates e heating value of the coal in question. The data are usually reported in rms of British thermal units (Btu.). Many other chemical and physical sts are available which provide data for special purposes bearing upon the utilization of coal.

The above testing procedures are rigidly controlled to provide uniform information for the coal industry. These methods are discusse in detail by Stanton (1939) and in a publication of the American Society for Testing Materials (1959). Standardized reaction analyses form the basis of American coal classification by rank as illustrated in Table 1. Note that data from the proximate analysis (fixed carbon and volatile matter) provide the means for distinguishing the higher rank coals. Th middle range of rank is classified mainly from the Btu analysis.

Although gross chemical studies are important, we agree with Seyler (1953) that "---coal systematists have almost entirely neglected the geological history and petrology of coal. They have ignored the fact that coal is a rock." For complete understanding of coal, it is therefore necessary to supplement the chemical analyses with petrographic examinations.

Petrographic Examination Of Coals

Coals, like other rocks, are natural components of the earth's crust. Each coal has persistent geological attributes as well as physica and chemical attributes. These properties are stratigraphic, structural sedimentary and paleobotanical. Petrographic examination enables us to correlate the geological properties with the other properties of the su stance.

The geological attributes are learned: (a) through examination of field relations existing between the coal and the adjacent sediments; a (b) through detailed study of the coal in terms of its sedimentary composition, both megascopically and microscopically. From the practical viewpoint, the resulting data are useful to the geologist and coal produce in studies of location, reserves, and ease of recovering coal from the earth. Academically, the information is needed to interpret the origin, deposition, and subsequent geological modifications of the coal bed.

Microscopic petrography is also used to determine the detailed physical composition of coals. This type of analysis augments and clari fies the overall physical and chemical data discussed earlier. Knowledg of the detailed physical composition is valuable to coal chemists and mar coal users.

Field Relationships

The importance of placing coal petrographic data into its proper perspective with reference to the accompanying sediments must not be underestimated. Much of the field data has immediate application. For

TABLE I.—CLASSIFICATION OF COALS BY RANK.[a]

Legend: FC = Fixed Carbon VM = Volatile Matter Btu = British thermal units

Class	Group	Limits of Fixed Carbon or Btu Mineral-Matter-Free Basis	Requisite Physical Properties
I. Anthracitic	1. Meta-anthracite	Dry FC, 98 per cent or more (Dry VM, 2 per cent or less)	Nonagglomerating[b]
	2. Anthracite	Dry FC, 92 per cent or more and less than 98 per cent (Dry VM, 8 per cent or less and more than 2 per cent)	
	3. Semianthracite	Dry FC, 86 per cent or more and less than 92 per cent (Dry VM, 14 per cent or less and more than 8 per cent)	
II. Bituminous[d]	1. Low volatile bituminous coal	Dry FC, 78 per cent or more and less than 86 per cent (Dry VM, 22 per cent or less and more than 14 per cent)	
	2. Medium volatile bituminous coal	Dry FC, 69 per cent or more and less than 78 per cent (Dry VM, 31 per cent or less and more than 22 per cent)	
	3. High volatile *A* bituminous coal	Dry FC, less than 69 per cent (Dry VM, more than 31 per cent); and moist[c] Btu, 14,000[e] or more	
	4. High volatile *B* bituminous coal	Moist[c] Btu, 13,000 or more and less than 14,000[e]	
	5. High volatile *C* bituminous coal	Moist Btu, 11,000 or more and less than 13,000[e]	Either agglomerating or nonweathering[f]
III. Subbituminous	1. Subbituminous *A* coal	Moist Btu, 11,000 or more and less than 13,000[e]	Both weathering and nonagglomerating
	2. Subbituminous *B* coal	Moist Btu, 9500 or more and less than 11,000[e]	
	3. Subbituminous *C* coal	Moist Btu, 8300 or more and less than 9500[e]	
IV. Lignitic	1. Lignite	Moist Btu, less than 8300	Consolidated
	2. Brown coal	Moist Btu, less than 8300	Unconsolidated

[a] This classification does not include a few coals which have unusual physical and chemical properties and which come within the limits of fixed carbon or Btu of the high-volatile bituminous and subbituminous ranks. All of these coals either contain less than 48 per cent dry, mineral-matter-free fixed carbon or have more than 15,500 moist, mineral-matter-free Btu.

[b] If agglomerating, classify in low-volatile group of the bituminous class.

[c] Moist Btu refers to coal containing its natural bed moisture but not including visible water on the surface of the coal.

[d] It is recognized that there may be noncoking varieties in each group of the bituminous class.

[e] Coals having 69 per cent or more fixed carbon on the dry, mineral-matter-free basis shall be classified according to fixed carbon, regardless of Btu.

[f] There are three varieties of coal in the high-volatile C bituminous coal group, namely: Variety 1, agglomerating and nonweathering; Variety 2, agglomerating and weathering; Variety 3, nonagglomerating and nonweathering.

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example, the ease of mining can be inferred from the geological information obtained about the sediments above and below the bed.

Coal is sometimes thin or missing in areas where sandstone rests directly upon the seam. A change in roof sediments may allow so minerals (pyrite especially) to penetrate the coal. Pyrite infiltration fr a sandstone roof locally can raise the sulfur content of the coal above limits tolerated for coking.

Field data also aid in correlating the coal bed from place to place. The criteria such as marker beds, plant or animal fossils, and special structural features may serve as guides to tell one coal from another or to interpret the original depositional conditions.

Normal geological description is used for this facet of coal petrography.

Megascopic Description

Examination of a coa seam with the unaided eye provides a physical description which is useful in relati the microscopical observati with the gross geological cha acteristics of the coal. Tw descriptions are desirable. The first is made of the bed in place. The second, a mo detailed description, may be made of coal samples in the laboratory.

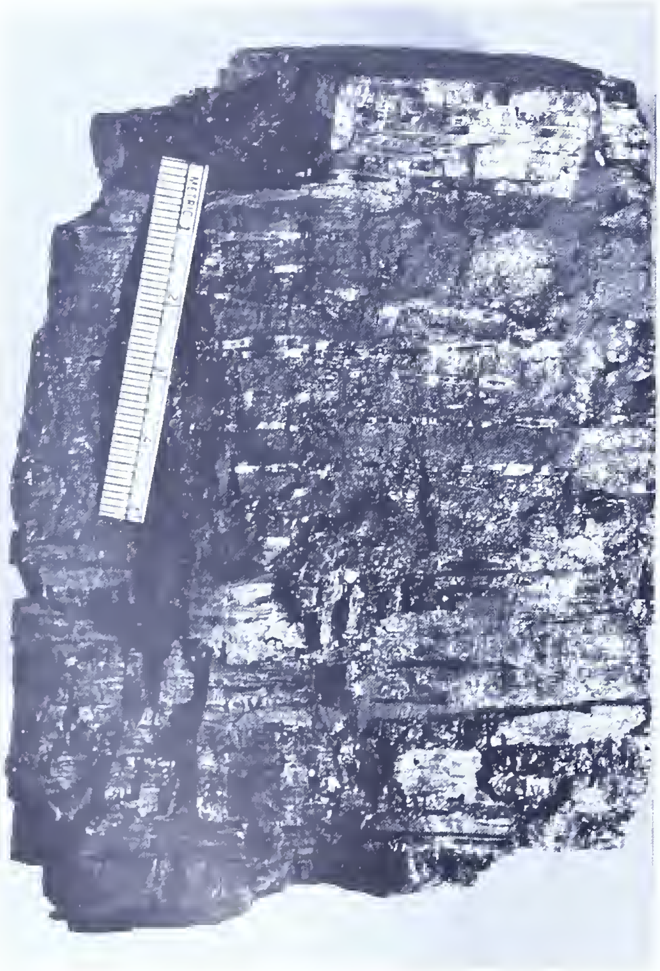


Figure 2. Coal from Tioga County showing bright anthraxylon bands embedded in a dull attritus.

The Pennsylvania Geological Survey employs the megascopic rminology developed by R. Thiessen of the U. S. Bureau of Mines 913 *et seq.*). Thiessen recognized that all normal coals consist of ack bands or lenticles of altered wood, bark and other related plant agments embedded in a matrix of finely comminuted and degraded or- nic matter (Figure 2). The bright black bands and lenticles are called *thraxylon.* The duller matter, in which the anthraxylon is embedded, termed the *attritus.* Often a third ingredient can be detected which sembles charred wood. This is *fusain.* In addition, layers of shaly al (commonly called "bone"), inorganic partings, and pyritic zones may recognized in the bed.

The vertical position and relative abundance of the above ingre- ents is recorded in accordance with the recommendations of the U. S. ological Survey (Schopf, 1950). To expedite analysis, a simple check rm is employed (Figure 3).

To measure a coal section in the field, a graduated tape is stened vertically to the cleaned coal face with the zero level at the permost part of the bed. In the first column of the check form, each rtical interval is noted. The field observer may subdivide the bed into many vertical intervals as he prefers, based upon similar appearing al in each unit or he can use specific uniformly measured intervals, ch as 1 inch, 1/10 foot, 6 inches, etc. The percentage of anthraxylon estimated for every designated interval. The approximate thickness of bands in the interval are also noted. Very often, two or more distinct ckness ranges may be present. Both are then checked on the form as ted in the examples given in Figure 3.

Luster of the attrital matrix may vary from very bright, approach- g that of the anthraxylon, to very dull. A subjective description of the ster helps to characterize the interval. Various benches in a coal bed e further differentiated by unlike fracture patterns, fresh surfaces ing exposed to determine this feature. Notes on fractures are recorded the check list (Figure 3) in the appropriate column. In addition a lumn is provided in which all observations of shaly beds, mineral atter, fusain and miscellaneous information are recorded.

Any interval is amenable to verbal description if desired. For ample, the bench 6 to 8 1/2 inches below the top of the seam recorded Figure 3 would be described as, "Abundant medium to thick anthraxylon nds in dull attritus having a conchoidal fracture." After every interval the coal bed is described, decisions may be reached from the record subdivide the bed into natural layers of similar coal types.

Accurately recorded megascopic descriptions are particularily lpful for recognizing the degree of uniformity within a coal seam. The

MEGASCOPIC DESCRIPTION

COUNTY Westmoreland
LOCATION 1500' E. 79° 45' 200' S. 40° 35'
MINE Springdale
ENTRY —
FIELD ☒ LABORATORY ☐

Upper Freepart
(COAL BED)
TOTAL THICKNESS $68\frac{3}{4}''$

PAGE 1 OF 3 PAGES
DATE 2−28−1958
COLUMN 36−2

DIP <1° STRIKE N20°W JOINT PATTERN—FACE N57°W BUTT N 20° E INITIALS E.F.K.

LEVEL FROM TOP OF COAL	ANTHRAXYLON (VITRAIN)								ATTRITUS (MATRIX)						FRACTURE					SUPPLEMENTARY NOTES
	ABUNDANCE				THICKNESS PERPENDICULAR TO BEDDING				LUSTER											PRESENCE OF MINERAL MATTER, FUSAIN, ETC. (USE ABUNDANCE TERMS FOR AMOUNTS OF FUSAIN)
INCHES	PREDOMINANT +60 %	ABUNDANT 30−60 %	MODERATE 15−30 %	SPARSE 0−15 %	THICK (5−50 M.M.) 1/2−2"	MEDIUM (2−5 M.M.) APPR. 1/4"	THIN (0.5−2 M.M.) APPR. 1/16"	MICRO (−0.5 M.M.) APPR. 1/32"	VERY BRIGHT	BRIGHT	MODERATELY BRIGHT	MODERATELY DULL	DULL	VERY DULL	SMOOTH	ROUGH	GRANULAR	CONCHOIDAL	CUBICAL	
Roof																				Gray shale—micaceaus
0−6			X			X→							X			X				
$6-8\frac{1}{2}$		X			←X								X					X		(Test example) See Page 9
$8\frac{1}{2}-11$				X			X	X					X			X				
$11-11\frac{1}{4}$	X				X													X		Single thick Anthraxylan band
$11\frac{1}{4}-17$				X	→X									X		X				Sulfur lenticle at $12\frac{1}{2}''$ } "Bane"
17−21				X		X	X						X			X				High−ash layer
21−26			X			X	X				X								X	Sparse fusain
26−30		X				X←				X←X									X	Fusain sparse ta absent at base
30−37	X					X					X								X	Gradatianal layer; Increase of size and amount of

ım characteristics also set that bed apart from others in the area - s aiding the geologist in correlation problems. The potential of this criptive technique in industry and science is not yet fully developed.

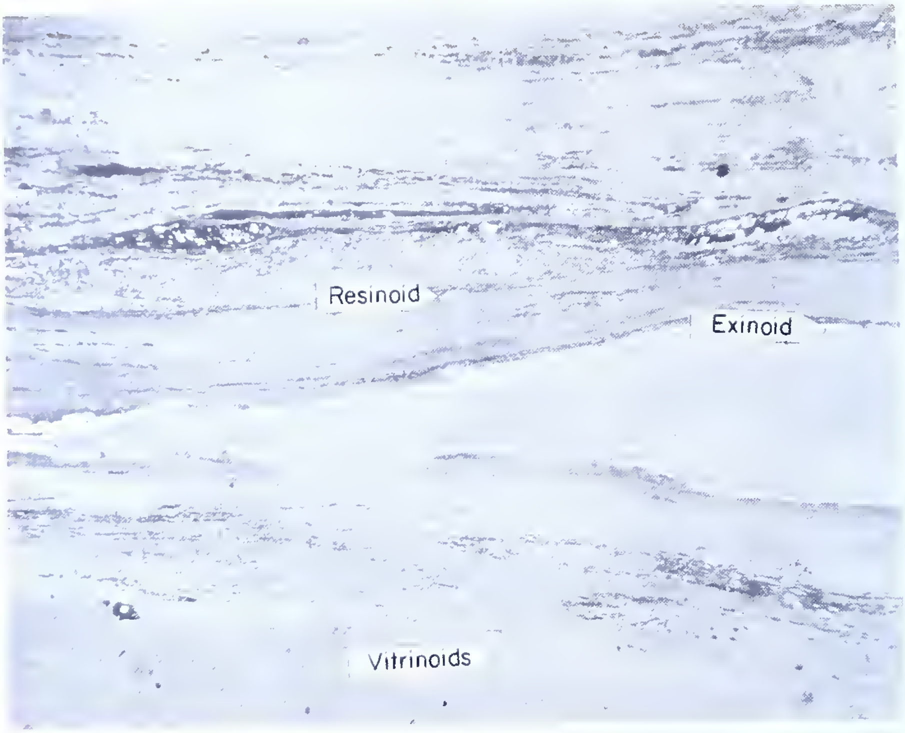
The field description is necessarily limited in scope and should supplemented by microscopical and chemical study in the laboratory m samples collected after the field examination is completed. After field description is made, samples may be collected. Blocks of coal collected representative of every interval of the bed at a given site. ch block is marked carefully in terms of its orientation and vertical ition in the column. In the laboratory, the blocks are split or cut tically. One half is preserved for chemical and physical tests; the er is embedded in plastic permitting one-inch cubes to be cut repre- ıtative of every one-inch interval of the coal. A surface perpendicular the bedding plane is ground and polished for examination by reflected ıt. At this point a routine low power (10x) analysis is made of the gascopic ingredients in each one-inch sample. The data thus provided ld quantitative expression to the field information gathered earlier.

Microscopic Analysis

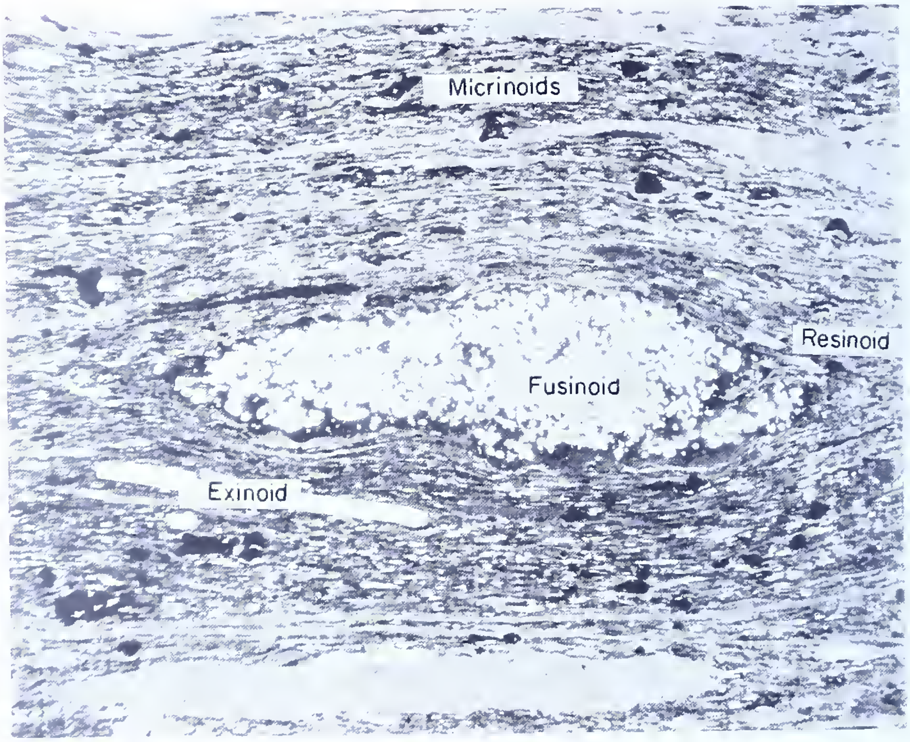
ıeral

Under the microscope, two distinct studies may be made. The st (maceral composition) describes the "organic minerals" present and suited to industrial application. The second analysis (sedimentary) cidates the botanical and depositional history of the bed. Examination analysis is accomplished with reflected light or transmitted light, two basic microscopical techniques. With reflected (incident) illu- ıation one examines the polished surface of coal blocks. This technique articularly valuable for higher rank coals and anthracite which are que even in very thin section. An intermediate magnification (100x) ısed. In the laboratory of the Pennsylvania Geologic Survey, oint-count technique (Cady,1958) is used.

Coals of medium or high volatile rank have the advantage in that y are transparent when an extremely thin slice is prepared and ex- ined with a standard microscope. Whereas bituminous coal entities are n in various tones of gray by reflected techniques, these thin sections eal fine structures of translucent coal substances in many shades of , yellow and brown. To prepare thin sections of the entire column, surface of each one-inch cube is reground and polished. The block is nented, polished surface down, to a glass slide with an epoxy resin. ess coal is then cut away with a diamond saw and the section care- y ground and honed until the appropriate thinness is obtained. Finally, over slip is cemented over the finished section to prevent oxidation of sample. A suitable thin section of bituminous coal generally is 6 - 8

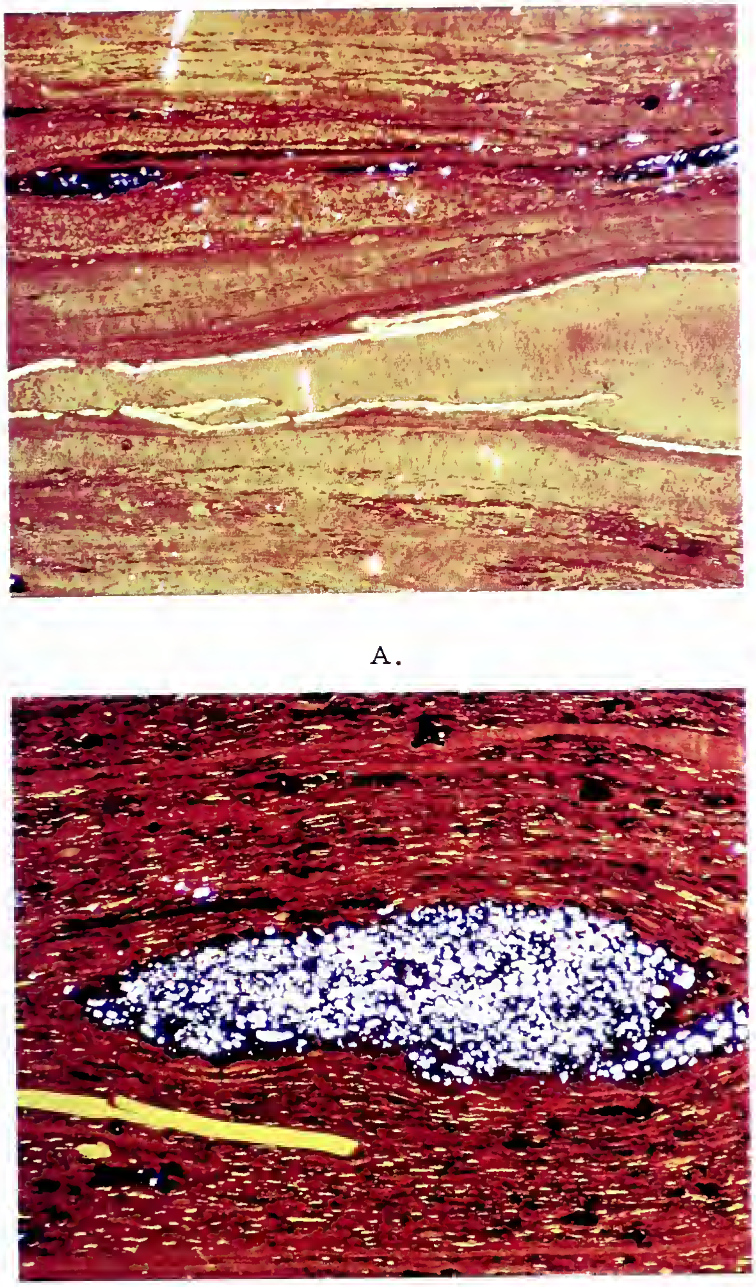


A. Bright Coal x 29



B. Dull Coal x 77

Figure 4. Microscopical components of coal (transmitted light)



A.

B.

Figure 5. Microscopical components of coal (See Figure 4 for legend)

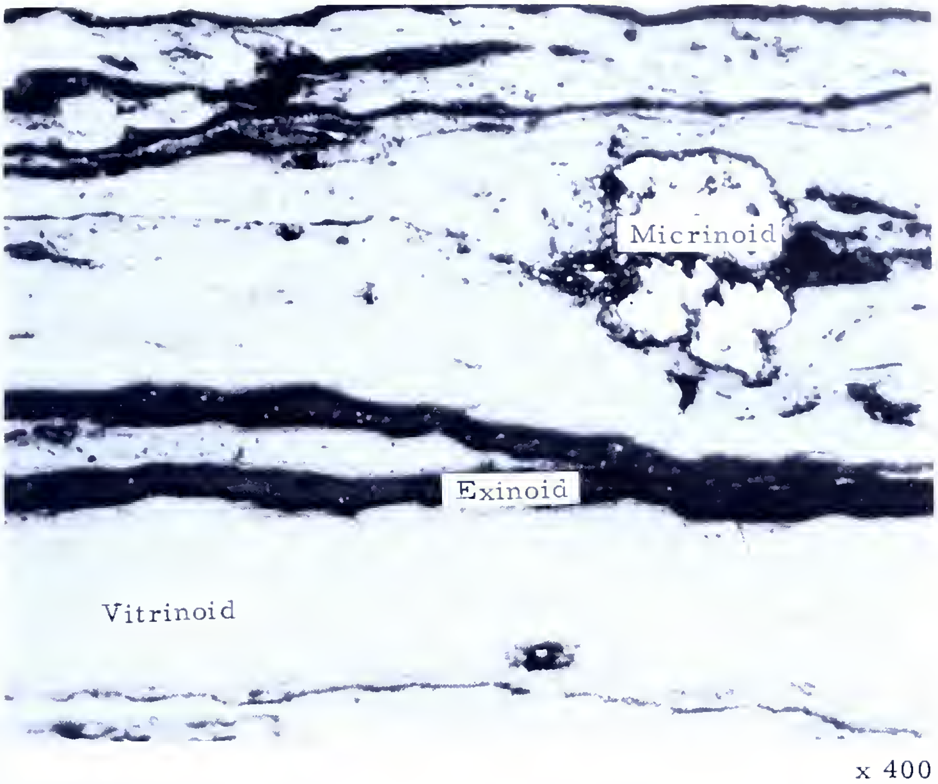


Figure 6

Reflected light photomicrograph. Differential light absorption makes more transparent components appear dark and opaque components white. Compare with transmitted light pictures (Figures 5a and 7).

EXPLANATION

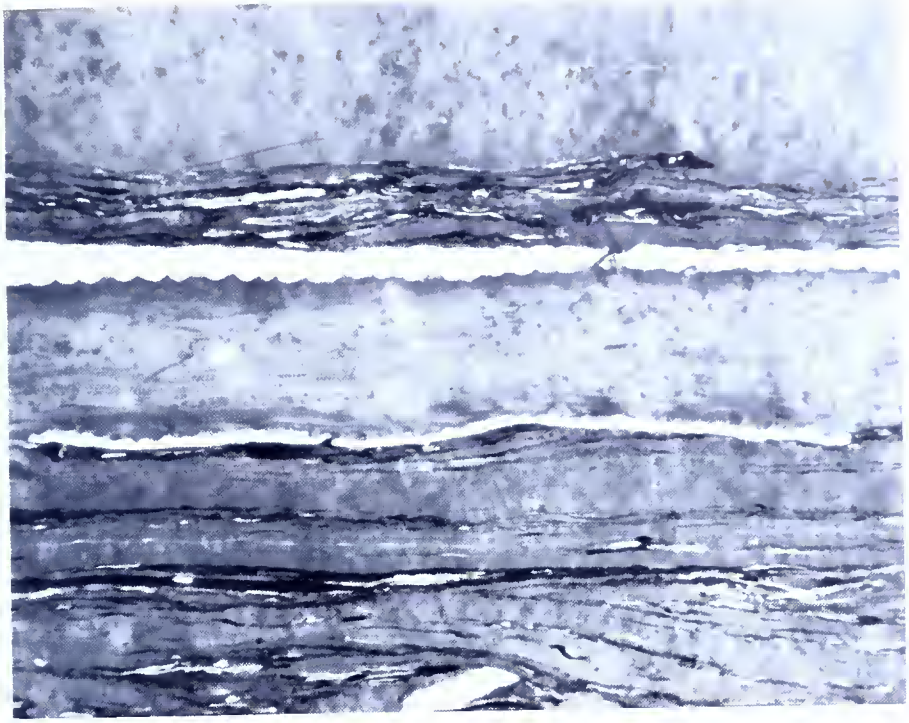
OF

COAL PHOTOMICROGRAPHS (TRANSMITTED LIGHT)

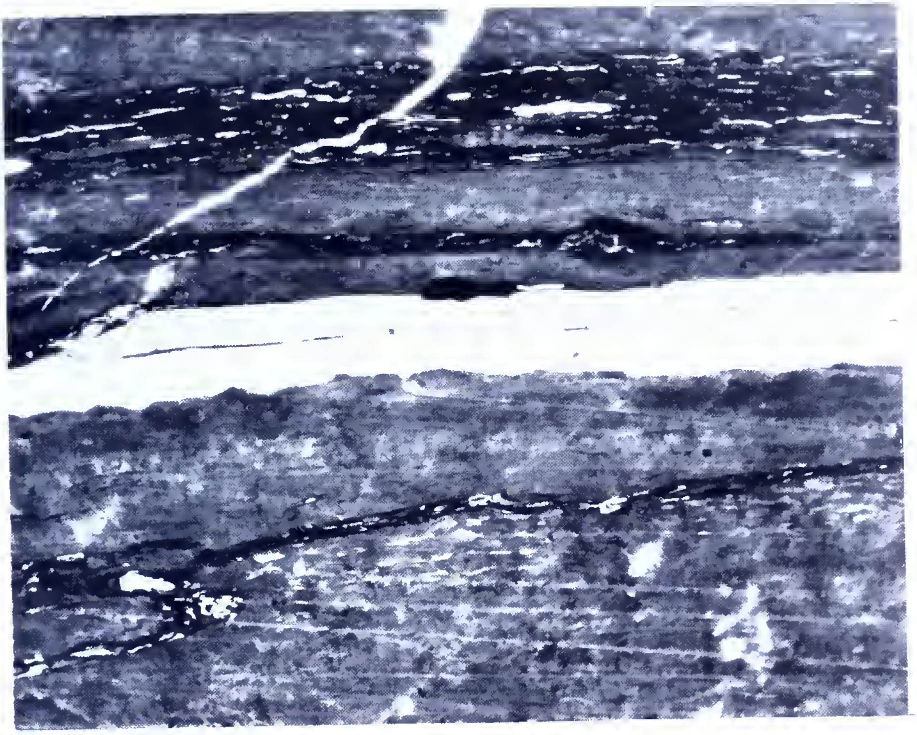
Figure 7

A. Vitrinoids and Exinoids. The top gray vitrinoid band is sometimes called collinite and the central band between the two very light exinoids is termed telinite. Botanically, the central strip is a section of a fern leaf with a thick cuticle (cutinite) on the upper surface and a thinner one on the lower. Cellular organization of the leaf was not destroyed during coalification.

B. Two exinoids are contrasted in the center of this photomicrograph. The upper of the two light bands is sporinite; the lower, cutinite. Some micrinoids are visible in the upper half of the field as black specks and bands.



A.



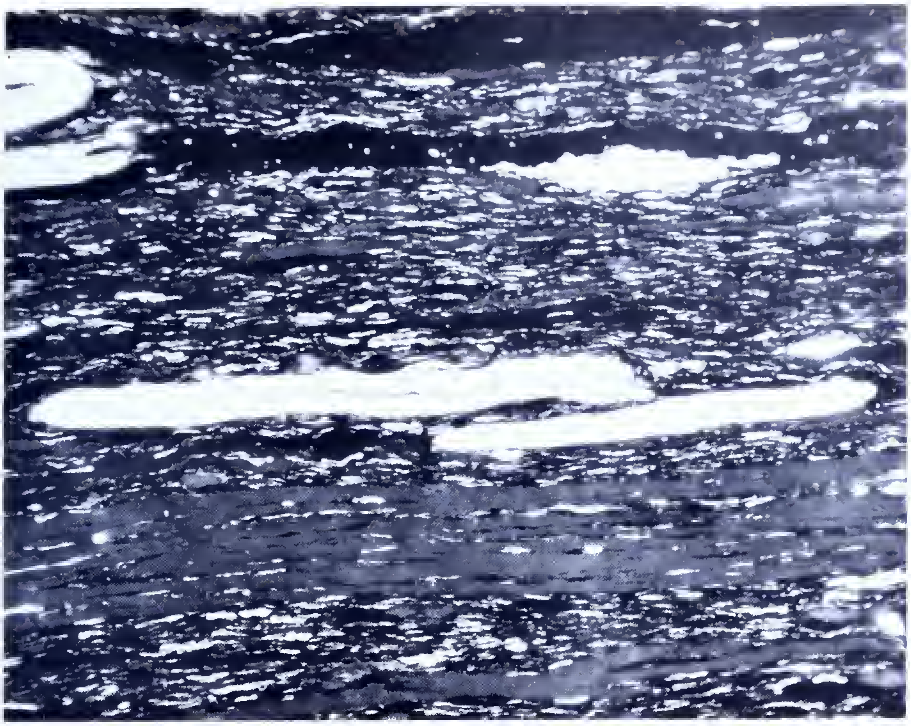
B.

Figure 7

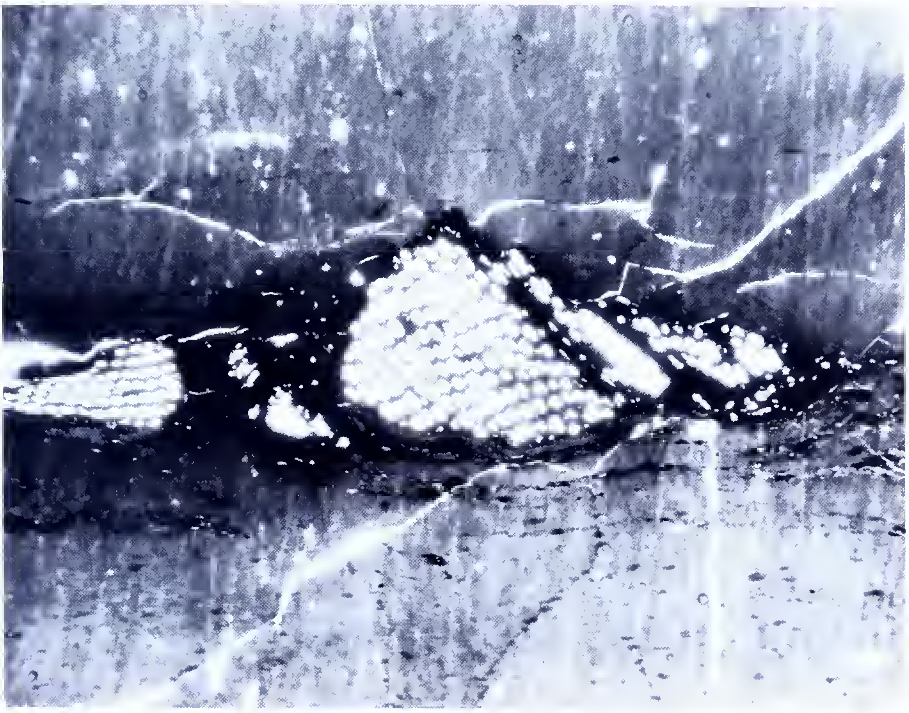
Figure 8

A. Attritus, or coal matrix, containing an intimate mixture of exinoids, micrinoids and vitrinoids. The exinoids are made up of large and small plant spores, sometimes with very ornate markings.

B. Fusain fragments (fusinoids) showing typical open plant cell structure. The opaque cell walls are somewhat obscured by reflections caused by mineral matter filling the cells. Most of the remaining entities are vitrinoids, the main components of anthraxylon fragments.



A.



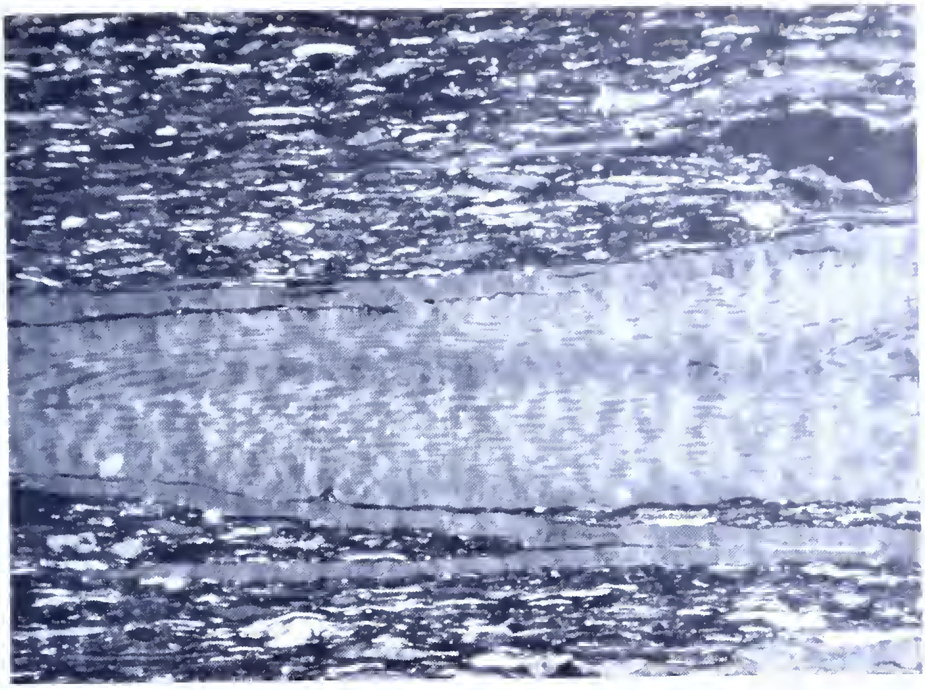
B.

Figure 8

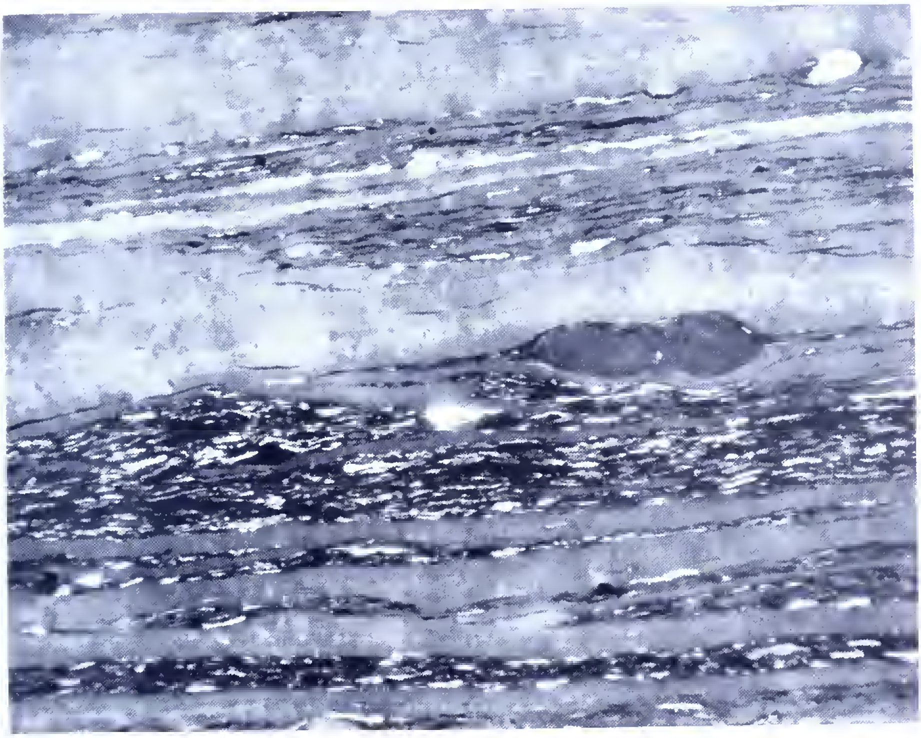
Figure 9

A. Anthraxylon embedded in attritus. The largest fragment is composed of two or three different vitrinoids.

B. Oval resinoid blebs in coal. The darker resinoids are part of the attrital matrix and the light resinoid is a part of the anthraxylon fragment. A marginal halo sometimes aids in identifying resinoids, as exhibited in the lighter member of this group.



A.



B.

Figure 9

microns in thickness (about one —three thousandth of an inch). Exam of coal as seen magnified in thin sections are shown in Figures 4 and Figure 6 illustrates a polished surface photomicrograph for comparis

For routine analysis, the slide is examined at 100 x magnificat A Whipple disk is employed in estimating quantities. For a detailed d sion of this and alternate techniques, the reader is referred to Cady (

Maceral Composition

Macerals are elementary coal components which may be recognized through the microscope (Stopes, 1935). Macerals are organic counterparts (analogs) of minerals — the discrete entities of rocks. I ly, each maceral should be defined as having specified physical and chemical properties. However, at the present level of our knowledge, individual maceral characteristics have only been approximately defin As more is learned, much greater use of this kind of coal analysis wil be possible.

Maceral group terms (Spackman, 1958) are employed by this laboratory wherever possible, although in some cases individual mace terms cannot be avoided. This procedure is employed to permit a uni compact terminology for anthracite and bituminous coals alike. The i portant maceral groups are:

Vitrinoids - The most commonly encountered microscopic components most coals. In bituminous coals these entities usually are transluc red to dark orange in transmitted light, or light to dark gray in reflected light. The group incorporates many related substances whi may differ in texture and size. Hence the group includes, for exam both translucent matrix and larger banded constituents (Figure 5 an One of the vitrinoids which lacks cellular structure is termed *collin* another showing plant cell structure has been designated *telinite*. T two macerals are shown in Figures 7a, 8b, and 9a. These special terms, however, will not be used in routine analysis.

Fusinoids - Microscopic entities which are opaque in thin section and white, or nearly so, in reflected light. These consist mostly of hig carbonized matter which retains at least some vestige of cellular o ganization as shown in Figures 5 and 8b. *Semi-fusinite* is a substa intermediate between vitrinoids and fusinoids. Chemically it may b more similar to the vitrinoids and is analysed separately for that re son.

Micrinoids - This group includes all opaque or nearly opaque organics other than the fusinoids. Micrinoids may be either minutely granul or massive but always have a reflectivity similar to the fusinoids w reflected light. In extremely thin sections a brown color is someti noted. These components are the black flecks and bands especially prominent in Figures 5b, 7b and 8a.

xinoids - In bituminous coals these are usually translucent to transparent yellow in transmitted light and dark gray to black in reflected light. The exinoids are waxy substances in the coal composed of spores (sporinite), plant cuticles (cutinite), and other substances. Substances identified as exinoids are shown in Figures 5, 7 and 8a. Sporinite and cutinite are contrasted in Figure 7b. Sporinite is slightly darker than cutinite due to a slight difference of color.

esinoids - These macerals may be yellow, orange, or deep red in thin section and are generally dark gray in reflected light. The resinoids consist of fossilized plant resins and related materials. These appear in Figure 9b as translucent oval blebs.

In addition, analyses include the quantitative amounts of inorgani constituents reported as mineral matter.

Sdimentary Analysis

The sedimentary analysis is simply a microscopic counterpart of te megascopic description discussed earlier. The terminology used is tat developed by Reinhart Thiessen of the U. S. Bureau of Mines (1913-147).

Anthraxylon - the coal ingredients derived from the wood tissues and cortex (bark) of plants. Anthraxylon (Figures 5a and 7a) consists of discrete strips or lenticles greater than 14 microns in the smallest dimension and of variable proportions. Remnants of cellular organization are often present (Theissen, Sprunk, and O'Donnell; 1931). Anthraxylon is composed primarily of the vitrinoids but variable amounts of resinoids and micrinoids are often present in these fragments. The word anthraxylon is derived from the two Greek words anthrax, meaning coal, and xylon meaning wood.

sain - this constituent, unlike anthraxylon or attritus (see below), represents a condition of preservation of many different plant tissues and organs. Woody tissues, leaf material etc. are preserved as charcoal-like remains. Fusain is opaque in thin section with original cellular organization intact or partially crushed. This substance (Figures 5b and 8b) can be recognized throughout the coal sequence - from peat through anthracite and is identical to the maceral components termed fusinoids.

tritus - that portion of coal in which anthraxylon and fusain are embedded. This matrix is composed of all kinds of degraded and triturated plant matter and includes; wood tissue and bark smaller than 14 microns, spores, cuticles, some resin and finely comminuted unidentifiable organic debris (Thiessen 1920, 1928). The attrital matrix is illustrated in Figures 5b, 8a and 9 filling the area between anthraxylon fragments.

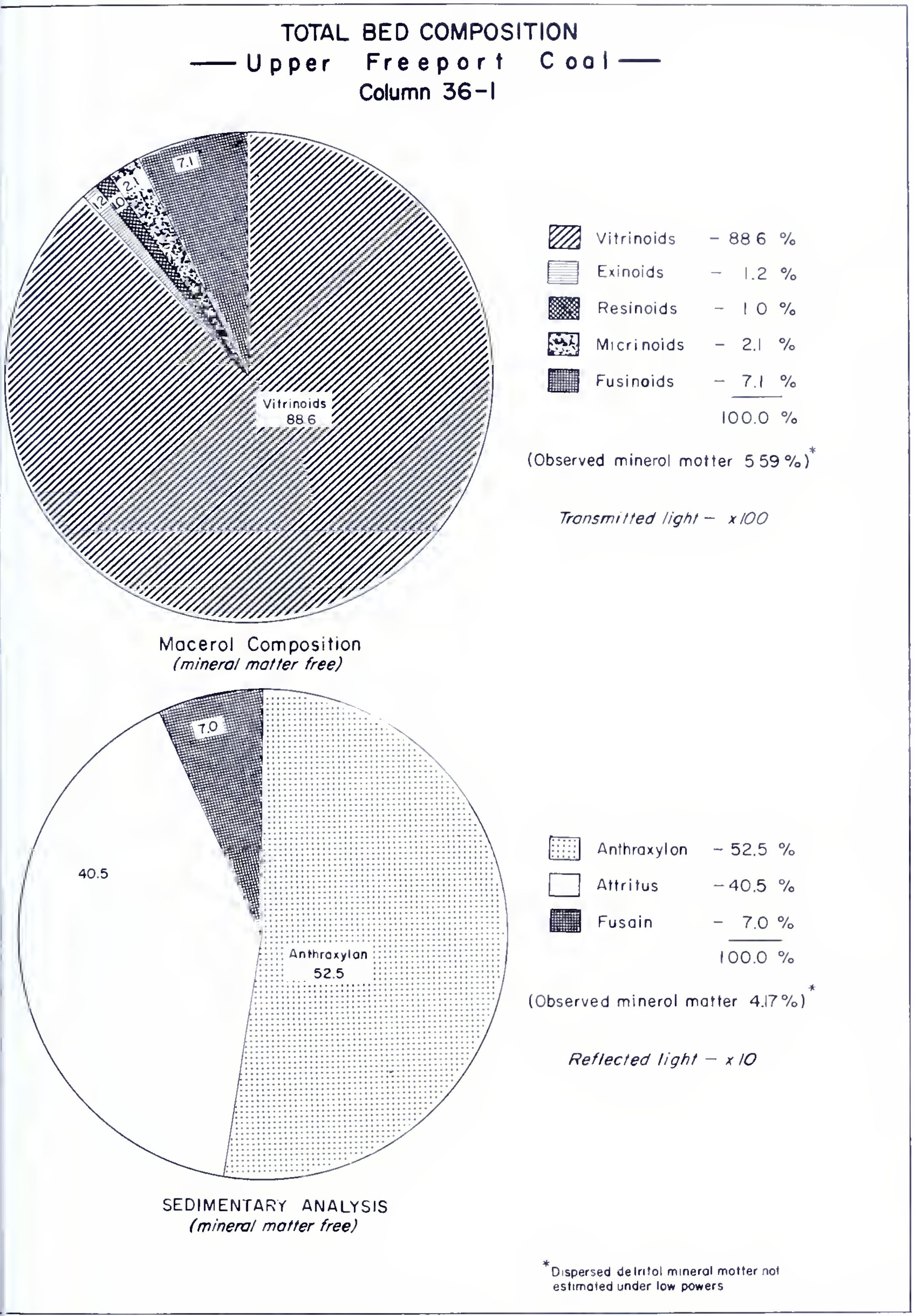
If this sedimentary constituent is examined using thin section techniques it may be classed as either translucent attritus or opaque attritus. Wher reflected light techniques are employed, a notation "gray" or "white" may be used.

The abundance of each of the above constituents controls the me scopic coal type of various zones within the coal bed. A "bright coal" m consist either of large quantities of anthraxylon and meager amounts of attritus, or of lesser proportions of anthraxylon with a corresponding increase of translucent ("gray") attritus. "Dull coal" (splint) contains sma quantities of anthraxylon and large quantities either of opaque attritus or of translucent attritus particularly rich in spores. Increased detrital mineral matter also causes a decrease in luster.

The dual microscopical analysis is used by this organization because of the potential for each analysis, the one primarily in geological investigations and the other in industrial application. Being based on present physical and chemical properties, maceral analysis has gained favor especially in Europe (Cady, 1958). The ability to correlate microscopic composition with coal utilization is largely responsible for this trend. Both analyses are required if coal quality (as determined by maceral analysis and other chemical tests) is to be related to the geological occurrence of coal.

As an example, a petrographic log of the Upper Freeport coal bed in Armstrong County is included in the appendix to this report. Figure 10 graphically summarizes the relative abundance of the organic constituents in this bed. This coal is currently used as a steam coal. It could, however, be considered as a reserve coal for coking. Through cleaning and blending, the steel industry can obtain maceral ratios required of metallurgical coking coals. The high fusinoid content of the uppermost seven inches (zones 1 and 2) of this coal would cause very gre difficulty in metallurgical coke production. However, the fusinoid conte (and mineral matter) can be reduced significantly by cleaning. The clea product could then be mixed with another high volatile bituminous coal having a low vitrinoid and high micrinoid and exinoid content. Desirable high volatile coking coal blends can be produced in this fashion from coal not ordinarily considered fit for coking.

As mentioned earlier, the full potential of coal petrography has not yet been realized. As this field develops, it will aid in the future effective mining, preparation and utilization of our Pennsylvania coals.



F ure 10. SUMMARY OF ORGANIC CONSTITUENTS IN A SECTION OF UPPER FREEPORT COAL

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APPENDIX

Petrography
Upper Freeport Coal

Column 36-1

Armstrong Mine
Armstrong County, Pennsylvania

INTRODUCTION

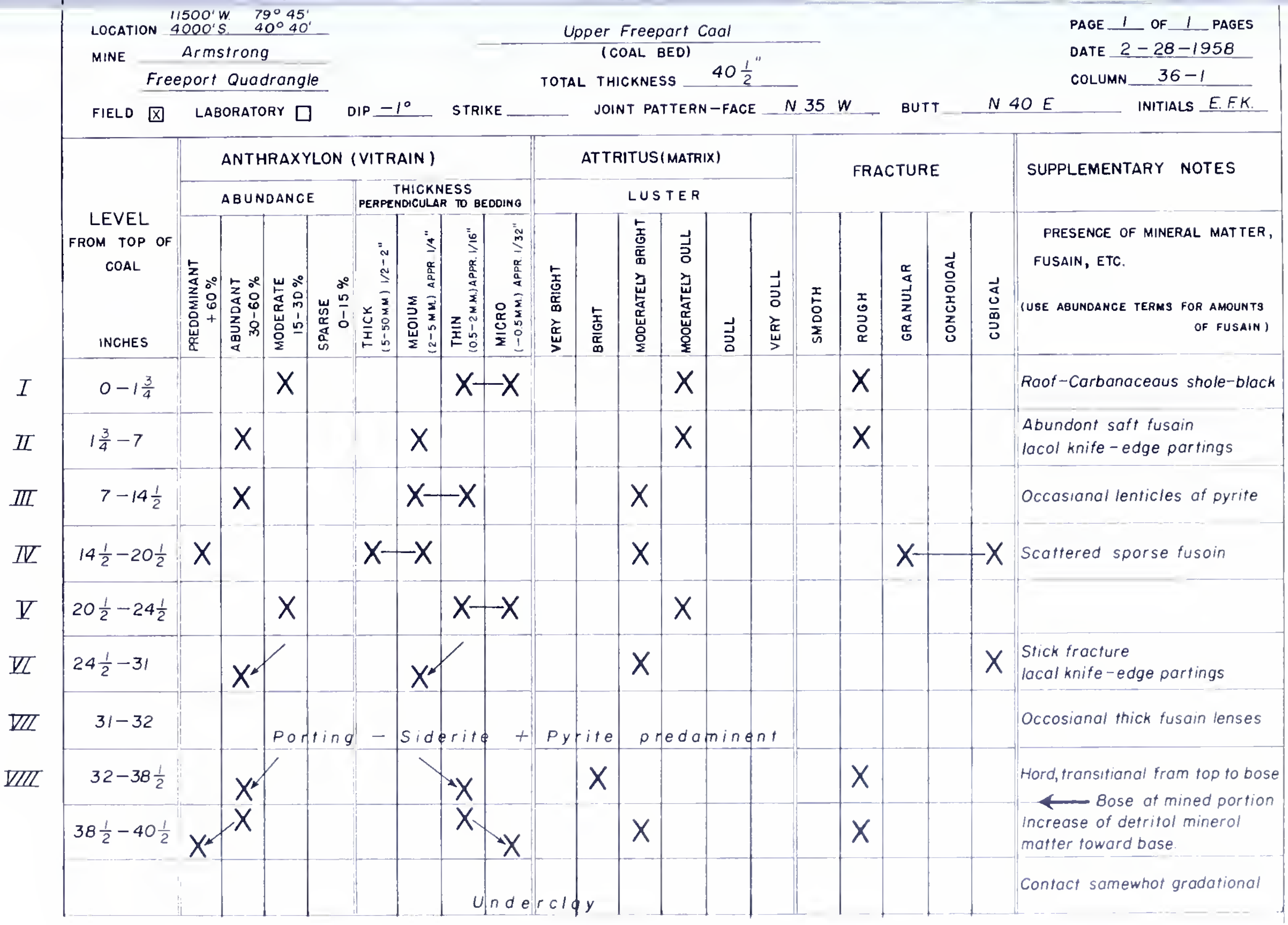
Coal column 36-1 was collected underground in the Upper Freeport Coal Bed approximately 9,000 feet north-east of the drift entrance the Armstrong Mine, Parks Township, Armstrong County, Pennsylvani, Although the character of the overburden at the specific site is not know drill records taken nearby indicate that the coal is overlain with about 5 feet of black to dark gray carbonaceous shale, 18 feet gray sandy shal and an undetermined thickness of sandstone. At the sample site the coa thickness was 40 1/2 inches, including the single prominent one-inch parting 9 inches above the base.

The coal is classified as a high volatile A bituminous coal. Co posite proximate and ultimate analyses by the United States Bureau of Mines were published earlier (Hughes, 1933) show the following compos tion:

U. S. Bureau of Mines Laboratory No. 85,770

	As received Percent	Air-Dry Percent	Dry, Ash fre Percent
PROXIMATE ANALYSIS			
Moisture	2.4	-	-
Volatile matter	35.0	35.8	38.7
Fixed carbon	55.3	56.7	61.3
Ash	7.3	7.5	-
ULTIMATE ANALYSIS			
Sulfur	2.4	2.5	2.7
Hydrogen	5.3	5.1	5.6
Carbon	75.8	77.7	84.0
Nitrogen	1.4	1.5	1.6
Oxygen	7.8	5.7	6.1
CALORIFIC VALUE			
Calories	7,572	7,756	8,389
British Thermal Units	13,630	13,960	15,100

In an overall sense, the coal has a fairly bright luster and lacks abrupt changes in lithology. Characteristics of the eight lithologically distinct layers recognized in the field are shown in the megascopic description (Appendix Figure 1). Laboratory data (Appendix Table 1) are averaged for each layer permitting evaluation of the maceral and sedimentary composition of each megascopic zone.



LOCATION 11500' W. 79° 45' 4000' S. 40° 40'
MINE Armstrong
Freeport Quadrangle
FIELD ☒ LABORATORY ☐ DIP -1° STRIKE ____

Upper Freeport Coal
(COAL BED)
TOTAL THICKNESS 40 1/2"
JOINT PATTERN-FACE N 35 W BUTT N 40 E

PAGE 1 OF 1 PAGES
DATE 2-28-1958
COLUMN 36-1
INITIALS E.F.K.

	LEVEL FROM TOP OF COAL	ANTHRAXYLON (VITRAIN)								ATTRITUS (MATRIX)						FRACTURE					SUPPLEMENTARY NOTES
		ABUNDANCE				THICKNESS PERPENDICULAR TO BEDDING				LUSTER											PRESENCE OF MINERAL MATTER, FUSAIN, ETC. (USE ABUNDANCE TERMS FOR AMOUNTS OF FUSAIN)
	INCHES	PREDOMINANT +60%	ABUNDANT 30-60%	MODERATE 15-30%	SPARSE 0-15%	THICK (5-50MM) 1/2-2"	MEDIUM (2-5MM) APPR 1/4"	THIN (0.5-2MM) APPR 1/16"	MICRO (-0.5MM) APPR 1/32"	VERY BRIGHT	BRIGHT	MODERATELY BRIGHT	MODERATELY DULL	DULL	VERY DULL	SMOOTH	ROUGH	GRANULAR	CONCHOIDAL	CUBICAL	
I	0-1 3/4			X				X	X				X				X				Raof-Carbanaceous shole-black
II	1 3/4-7		X				X						X				X				Abundont saft fusain lacal knife-edge partings
III	7-14 1/2		X				X	X				X									Occasianal lenticles af pyrite
IV	14 1/2-20 1/2	X				X	X					X						X		X	Scattered sporse fusoin
V	20 1/2-24 1/2			X				X	X				X								
VI	24 1/2-31		X				X					X								X	Stick fracture lacal knife-edge partings
VII	31-32			Porting - Siderite + Pyrite predaminent																	Occosianal thick fusain lenses
VIII	32-38 1/2		X					X			X						X				Hord, transitianal fram top to bose ← Bose af mined portion
	38 1/2-40 1/2	X	X					X	X			X					X				Increase of detritol minerol matter toward base.
								Underclay													Contact samewhot gradational

Figure 1.

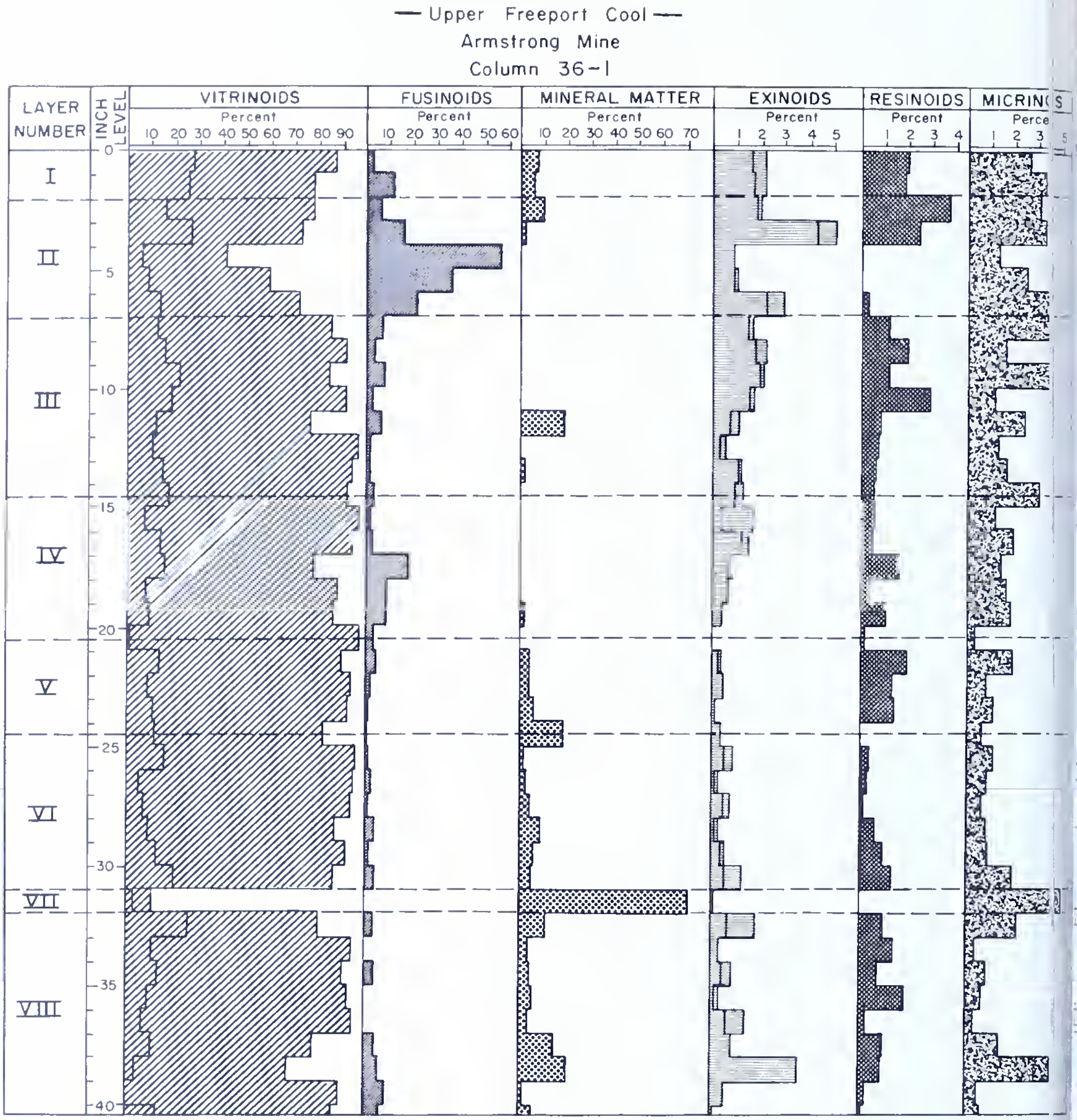


Figure 2. GRAPHIC LOG, MACERAL COMPOSITION

— Upper Freeport Coal —
Armstrong Mine
Column 36-1

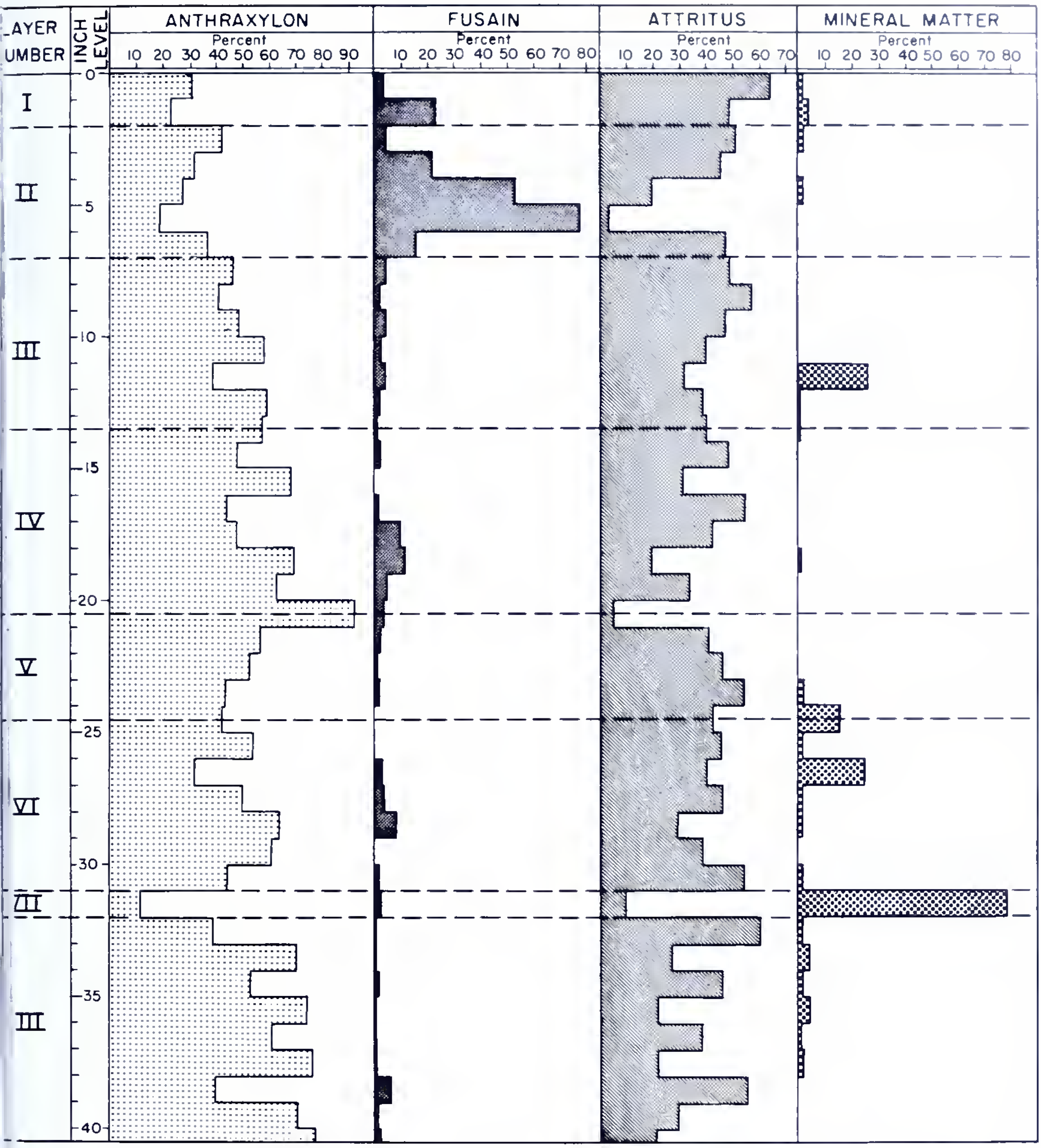


Figure 3. GRAPHIC LOG, SEDIMENTARY ANALYSIS

Graphic logs, reproduced as Appendix Figures 2 and 3, were pr- pared from the summarized laboratory data to illustrate the gradational nature of the coal, and also to facilitate detailed inch-by-inch compariso of the two types of analytical information. The summary data sheets, from which all graphs and tables were prepared, are appended.

In this petrographic examination, the vitrinoids were subdivided into two categories. Vitrinoid column D includes those macerals having a dark red to brown tone whereas column L combines the red to yellow vitrinoid macerals. In addition, semi-fusinite was treated as vitrinoid material because the microscopically determined properties of the component in this bed more closely fit the vitrinoids than the more highly carbonized fusinoids. The exinoids were recorded either as sporinite or cutinite depending on the botanical identification. For practical applications, these finer subdivisions may be disregarded.

A notation is necessary concerning the composition of the partin (Zone VII). Microscopically this zone can be separated into three layers Thin layers of detrital silt and clay bound the upper and lower limits of the central thick layer composed primarily of siderite ($FeCO_3$). In this case, the presence of siderite is interpreted as an indication that open water was present in which there was sufficient oxygenation to precipita the carbonate. In general, carbonate is removed from solution as CO_2 in the reducing environment of a swamp.

—Upper Freeport Coal—
Armstrong Mine
Column 36-1

		MACERAL*					SEDIMENTARY ANALYSI			
ZONE	LEVEL	Vitrinoids	Exinoids	Resinoids	Micrinoids	Fusinoids	Anthraxylon	Attritus	Fusain	min ma
I	0-2"	85.94	2.31	2.00	3.07	6.68	27.3	57.4	12.9	
II	2-7"	66.03	2.40	1.32	2.92	27.33	31.2	34.0	33.9	
III	7-15"	91.01	1.47	1.21	2.50	3.81	49.9	44.5	2.1	
IV	15-20"	89.00	0.97	0.77	1.57	7.69	58.4	36.4	5.0	
V	20-25"	95.73	0.31	0.96	0.96	2.04	57.3	37.8	1.6	
VI	25-31"	95.12	0.66	0.57	1.03	2.62	50.8	42.1	2.7	
VII	31-32"	Parting - Siderite and Pyrite						Parting		
VIII	32-40 1/2"	92.85	1.20	0.81	1.17	3.97	62.4	35.3	1.2	

*Calculated mineral matter free.

Table 1. ZONAL ANALYSES

COUNTY Armstrong
LOCATION 11,500' W. 79° 35' 4,000' S. 40° 40'
MINE Armstrong
THIN SECTION ☒ POLISHED SURFACE ☐

LABORATORY DESCRIPTION

Upper Freeport
(COAL BED)

SHEET 1
OF 5 SHEETS.
COLUMN 36-1
SAMPLE ☒ NORMAL ☐ CRUSHED
EFK
INITIALS

INTERVAL	MICROSCOPIC DESCRIPTION (macerals)								MINERAL MATTER		SEDIMENTARY ANALYSIS (constituents)				SUPPLEMENTARY NOTES
	VITRINOIDS		EXINOIDS		RESINOIDS	MICRINOIDS	FUSINOIDS				ANTHRAXYLON	ATTRITUS		FUSAIN	
inches ☒ cm. ☐	D	L	SPORINITE	CUTINITE			SEMI-FUSINITE	FUSINITE				TRANSLUCENT	OPAQUE		
0 – 1	27.32	59.27	1.64	0.50	1.94	2.58		2.03	4.72	1.6	30.3	65.2		2.9	
– 2	25.36	52.25	1.66	0.61	1.89	3.29		10.73	4.21	3.3	24.3	49.5		22.9	
– 3	15.96	61.80	1.81	0.16	3.70	3.09		5.59	7.89	2.2	41.5	52.0		4.3	
– 4	26.88	45.48	4.37	0.73	2.40	3.27		15.07	1.80	0.2	32.3	45.6		21.9	
– 5	6.91	34.70	0.80	–	0.05	1.27		56.13	0.14	1.2	27.7	19.8		51.3	
– 6	9.95	49.89	0.86	0.07	—	2.50		36.11	0.64	0.4	18.6	4.0		77.0	
– 7	13.32	57.57	2.24	0.69	0.29	4.17		20.82	0.30	0.5	36.0	48.5		15.0	
– 8	12.64	73.32	1.44	0.16	1.14	4.33		6.69	0.22	0.2	46.1	49.1		4.6	
– 9	15.52	75.39	1.85	0.36	1.97	1.54		3.30	0.07	0.2	41.0	57.6		1.2	
– 10	22.14	62.54	2.00	0.06	1.16	4.21		7.35	0.54	0.3	48.0	48.4		3.3	
TOTALS	176.58	572.21	18.67	3.34	14.54	30.31		163.82	20.53	10.1	345.8	439.7		204.4	
PERCENT															

SUMMARY

LABORATORY DESCRIPTION

COUNTY Armstrong

LOCATION 11,500' W. 79° 35'
4,000' S. 40° .0'

MINE Armstrong

THIN SECTION ☒ POLISHED SURFACE ☐

Upper Freeport

(COAL BED)

SHEET 2

OF 5 SHEETS.

COLUMN 36-1

SAMPLE ☒ NORMAL ☐ CRUSHED

EFK INITIALS

INTERVAL inches ☒ cm. ☐	MICROSCOPIC DESCRIPTION (macerals)								MINERAL MATTER		SEDIMENTARY ANALYSIS (constituents)				SUPPLEMENTARY NOTES
	VITRINOIDS		EXINOIDS		RESINOIDS	MICRINOIDS	FUSINOIDS				ANTHRAXYLON	ATTRITUS		FUSAIN	
	D	L	SPORINITE	CUTINITE			SEMI-FUSINITE	FUSINITE				TRANSLUCENT	OPAQUE		
10 - 11	18.82	73.33	1.51	0.17	2.79	1.02		1.79	0.57	—	58.2	40.0		1.8	
- 12	12.07	60.54	0.69	0.34	0.71	2.36		5.09	18.20	26.1	39.1	31.8		3.0	Fusain, filled with pyrite
- 13	11.16	85.05	0.31	0.14	0.60	1.22		1.41	0.11	—	59.6	39.6		0.8	
- 14	15.09	79.12	1.11	0.09	0.57	1.66		1.38	0.98	0.6	58.6	40.2		0.6	
- 15	17.27	75.18	0.85	0.38	0.50	3.05		2.68	0.09	0.5	48.5	49.8		1.2	
- 16	7.60	87.91	0.35	1.22	0.50	1.12		1.10	0.20	0.4	68.2	31.2		0.2	
- 17	14.50	79.18	1.26	0.19	0.48	1.96		2.14	0.29	0.3	43.8	55.3		0.6	
- 18	15.89	62.10	0.65	0.09	1.52	1.43		17.90	0.42	—	47.4	42.9		9.7	
- 19	8.36	80.43	0.59	0.03	0.32	1.51		8.41	0.35	0.5	69.8	18.9		10.8	
- 20	9.96	76.95	0.44	0.01	1.01	1.79		8.74	1.10	—	62.4	33.8		3.8	
TOTALS	130.72	759.79	7.76	2.66	9.00	17.12		50.64	22.31	28.4	555.6	383.5		32.5	
PERCENT															

LABORATORY DESCRIPTION

COUNTY Armstrong
LOCATION 11,500' W. 79° 35' 4,000' S. 40° 40'
MINE Armstrong
THIN SECTION ☒ POLISHED SURFACE ☐

Upper Freeport
(COAL BED)

SHEET 3
OF 5 SHEETS.
COLUMN 36.1
SAMPLE ☒ NORMAL ☐ CRUSHED
EFK
INITIALS

INTERVAL inches ☒ cm. ☐	MICROSCOPIC DESCRIPTION (macerals)								MINERAL MATTER		SEDIMENTARY ANALYSIS (constituents)				SUPPLEMENTARY NOTES
	VITRINOIDS		EXINOIDS		RESINOIDS	MICRINOIDS	FUSINOIDS				ANTHRAXYLON	ATTRITUS		FUSAIN	
	D	L	SPORINITE	CUTINITE			SEMI-FUSINITE	FUSINITE				TRANSLUCENT	OPAQUE		
20 - 21	0.23	96.14	—	0.04	0.08	0.31		3.15	0.05	—	92.1	4.7		3.2	
- 22	13.99	74.64	0.29	0.08	1.90	1.87		3.76	3.47	0.1	56.4	41.3		2.2	
- 23	8.78	84.30	0.36	0.04	1.27	0.76		1.24	3.25	—	52.8	46.5		0.7	
- 24	10.22	82.03	0.18	0.02	1.31	1.04		0.85	4.35	1.4	43.0	53.8		1.8	
- 25	11.92	70.35	0.43	0.01	—	0.56		0.62	16.11	15.9	42.0	42.1		—	detrital mineral matter
- 26	16.23	79.15	0.54	0.26	0.23	1.08		1.24	1.27	0.2	54.3	45.4		0.1	
- 27	5.50	88.97	0.14	0.11	0.22	0.81		2.21	2.04	25.2	31.2	39.8		3.8	
- 28	7.07	87.44	0.47	0.29	0.11	0.50		1.66	2.46	0.4	49.6	46.3		3.7	
- 29	8.96	78.46	0.21	0.01	0.59	0.81		4.11	6.85	0.3	64.5	27.9		7.3	
- 30	13.07	78.58	0.39	0.11	0.87	0.86		1.57	4.55	0.1	61.5	38.4		—	
TOTALS	95.97	820.06	3.01	0.97	6.58	8.60		20.41	44.40	43.6	547.4	386.2		22.8	
PERCENT															

SUMMARY

LABORATORY DESCRIPTION

COUNTY Armstrong
LOCATION 11,500' W. 79° 35' 4,000' S. 40° 40'
MINE Armstrong
THIN SECTION ☒ POLISHED SURFACE ☐

Upper Freeport
(COAL BED)

SHEET 4
OF 5 SHEETS.
COLUMN 36-1
SAMPLE ☒ NORMAL ☐ CRUSHED
EFK
INITIALS

INTERVAL	MICROSCOPIC DESCRIPTION (macerals)								MINERAL MATTER		SEDIMENTARY ANALYSIS (constituents)				SUPPLEMENTARY NOTES
	VITRINOIDS		EXINOIDS		RESINOIDS	MICRINOIDS	FUSINOIDS				ANTHRAXYLON	ATTRITUS		FUSAIN	
inches ☒ cm. ☐	D	L	SPORINITE	CUTINITE			SEMI-FUSINITE	FUSINITE				TRANSLUCENT	OPAQUE		
30 - 31	20.43	66.38	0.51	0.76	1.29	1.88		4.36	4.39	0.2	44.2	54.4		1.2	
- 32	3.69	7.62	0.13	0.01	—	15.00		0.69	72.86	78.7	10.2	9.1		2.0	Parting: siderite+pyrite
- 33	26.32	54.10	0.63	1.24	0.99	2.04		3.39	11.29	0.5	38.7	60.2		0.6	
- 34	11.04	83.57	0.33	0.05	1.35	0.36		0.35	2.95	3.1	70.3	26.0		0.6	
- 35	13.49	76.82	0.46	0.39	0.64	0.79		4.27	3.14	0.5	52.6	45.8		1.1	
- 36	9.57	83.75	0.20	0.11	1.79	0.51		0.39	3.68	3.7	74.9	21.4		—	
- 37	7.39	87.09	0.63	0.77	0.19	0.28		0.46	3.19	0.3	61.3	38.4		—	
- 38	10.71	68.08	0.85	0.02	0.79	1.34		4.75	13.46	1.6	76.7	21.5		0.2	
- 39	4.99	62.64	3.69	—	0.77	3.53		5.38	19.00	—	39.1	55.2		5.7	
- 40	0.36	89.00	0.57	—	0.18	0.45		7.95	1.49	—	70.7	28.6		0.7	
TOTALS	107.99	679.05	8.00	3.35	7.99	26.18		31.95	135.45	88.6	538.7	360.6		12.1	
PERCENT															

LABORATORY DESCRIPTION

COUNTY Armstrong
LOCATION 11,500' W. 79° 35' 4,000' S. 40° 40'
MINE Armstrong
THIN SECTION ☒ POLISHED SURFACE ☐

Upper Freeport
(COAL BED)

SHEET 5
OF 5 SHEETS.
COLUMN 36-1
SAMPLE ☒ NORMAL ☐ CRUSHED
EFK INITIALS

INTERVAL	MICROSCOPIC DESCRIPTION (macerals)								MINERAL MATTER		SEDIMENTARY ANALYSIS (constituents)				SUPPLEMENTARY NOTES
	VITRINOIDS		EXINOIDS		RESINOIDS	MICRINOIDS	FUSINOIDS				ANTHRAXYLON	ATTRITUS		FUSAIN	
inches ☒ cm. ☐	D	L	SPORINITE	CUTINITE			SEMI-FUSINITE	FUSINITE				TRANSLUCENT	OPAQUE		
40 – 41	13.67	72.85	0.10	0.02	0.03	0.51		6.22	6.60	0.2	77.8	20.0		2.0	
– 42						Base of Seam									
– 3															
– 4															
– 5															
– 6															
– 7															
– 8															
– 9															
– 0							SEAM TOTALS								
TOTALS	524.93	2903.96	37.54	10.34	38 14	82.72		273.08	2.29	170.9	2065 3	1590.0		273 8	
PERCENT	12 80	70.83	0.92	0.25	0 93	2.02		6.66	5.59	4.17	50.37	38 78		6.68	
	83.63		1.17												